Flocculation, Optics and Turbulence in the Community Sediment Transport Model System: Application of OASIS Results

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LONG-TERM GOALS

The goal of this research is to develop greater understanding of the how the flocculation of fine-grained sediment responds to turbulent stresses and how this packaging of sediment affects optical and acoustical properties in the water column. Achieving these goals will improve the skill of sediment transport models and their validation and hence visibility.

OBJECTIVES

1. Quantify the effects of aggregation dynamics on the size distribution of particles in the bottom boundary layer;

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2. Quantify how changes in particle packaging affect the optical and acoustical properties of the water column.

3. Develop and test a capability within the Community Sediment Transport Model System (CSTMS) to predict inherent optical properties based on modeled sediment concentration within the benthic boundary layer.

APPROACH

Our proposed modeling strategy works on three basic premises. First, CSTMS should treat small (< 16 μm) single grains as a single cohesive/aggregating pool. The single-grain population in this pool would have its own underlying, time-invariant size distribution, while flocs would add or subtract mass from this single-grain population. Flocs would be divided into a micro-floc pool that sinks at 0.1 mm/s and a macro-floc pool that sinks at 1 mm/s. Second, CSTMS should treat larger single grains as non-cohesive. And finally, because optical properties and sediment flux are more sensitive to floc fraction, which is the fraction of the total suspended mass contained within flocs, than to floc size, CSTMS should focus on modeling floc fraction rather than floc size.

The basic behavior of the model should be to drive mass out of macro-flocs at high stress, and to drive mass into macro-flocs at high concentration and low stress. A mathematical form that captures these behaviors is

$$f_{\max} = 1 - \left(\frac{k_f + \left(\frac{G^r}{k_G + G^r} \right) C}{k_f + C} \right)$$

In this equation, f_{max} is the maximum macro-floc mass fraction for a given small-scale shear, G, and sediment mass concentration, C. In order, the parameters k_f, k_G, and r specify the concentration at which macro-floc fraction increases rapidly, the shear at which macro-floc fraction decreases rapidly, and the sensitivity of macro-floc fraction to small-scale shear. Calibration of these coefficients would rely on theory and observations from our own work as well as on published studies. Linked formulae similarly would assign mass to the micro-floc and single-grain fractions in a way that conserves overall sediment mass. Such formulations have been used to model biological processes in ROMS (the model underlying CSTMS), so significant experience exists regarding implementation.

In order to implement this scheme, at each grid point at each time, the model would evaluate f_{max}. If $f < f_{max}$, then mass would flow out of single-grain and micro-floc pools into macro-flocs. If $f > f_{max}$, then mass would flow out of macro-floc pool into micro-floc and single-grain pools. These transfers could be handled several ways: instantaneous equilibrium, exponential asymptote toward equilibrium, or a fully time-dependent solution. This component of CSTMS would track small, cohesive optically active material. Another module would treat large sediment particles as non-cohesive.

This model would provide estimates of the concentration and size distribution of small, optically active particles as well as the concentration of flocs and large single grains. These outputs would serve as

inputs to a module that generates estimates of optical properties in the water column (For particulate attenuation see, Boss et al., 2009).

WORK COMPLETED

Since the beginning to this phase of our project (1/1/2010), we has spent time analyzing our extensive field data (collected in the previous phase) developing further relationships between stress, particle mass, optical and acoustical properties in the vein of further constraining the modules that will be implemented in the CSTMS.

RESULTS

Paul Hill led a study on the relationship between beam attenuation and particulate mass incorporating all the published relationships available (Hill et al., in press). Analysis showed that the mass specific beam attenuation in the literature can largely be explained by aggregation (keeping $c_p/mass$ approximately constant) and acceptance angle of beam transmissometer (resulting in $c_p/mass$ decreasing with mass) since mass and average particle size correlate positively in the bottom boundary layer (Fig. 1).

In a study led by Wayne Slade, we found that in the bottom boundary layer the spectral slope of backscattering (which can be measured from autonomous platforms or for extended periods of time on mooring, when equipped with copper shutters) can provide information on the particulate size distribution (necessary to model settling dynamics of particles, Fig. 1). This result is of fundamental importance since the PSD is a crucial input needed to obtain settling velocities of the non-aggregated portion of the suspended mass (Fig. 2).

In addition we have found that we could use the ratio of beam attenuation to LISST derived total volume is as an indicator for the degree of aggregation in the lab and field. When the ratio is low, aggregate dominate while when it is high single grain dominate.

We are now in a position to use our observations of flocculated size distributions and their response to stress to implement and test models that convert predictions of suspended particulate mass into predictions of the optical properties in bottom boundary layers. Chris Sherwood of USGS in Woods Hole is taking the lead on this work.

IMPACT/APPLICATIONS

The high-resolution time series of particle, optical, and acoustical properties will enhance understanding of the rates and mechanisms by which the water column clears following storm events. The development of a floc module for CSTMS will enable the implementation of a module that converts sediment to optical properties. The latter advance will provide the sedimentology community with a simple tool to test their model predictions against the most ubiquitous measurement of suspended matter in coastal waters, and it will lead to prediction of in-water optical properties based on predictions of seabed stress.

RELATED PROJECTS

A graduate student (Clementina Russo) is funded to study the link between acoustical and optical properties during OASIS (N000140910577 to E. Boss).

PUBLICATIONS

Hill, P., E. Boss, J. P. Newgard, B. A. Law and T. G. Milligan, Observations of the sensitivity of beam attenuation to particle size in a coastal bottom boundary layer, *submitted to J. Geophys. Res.*[unpublished, refereed].

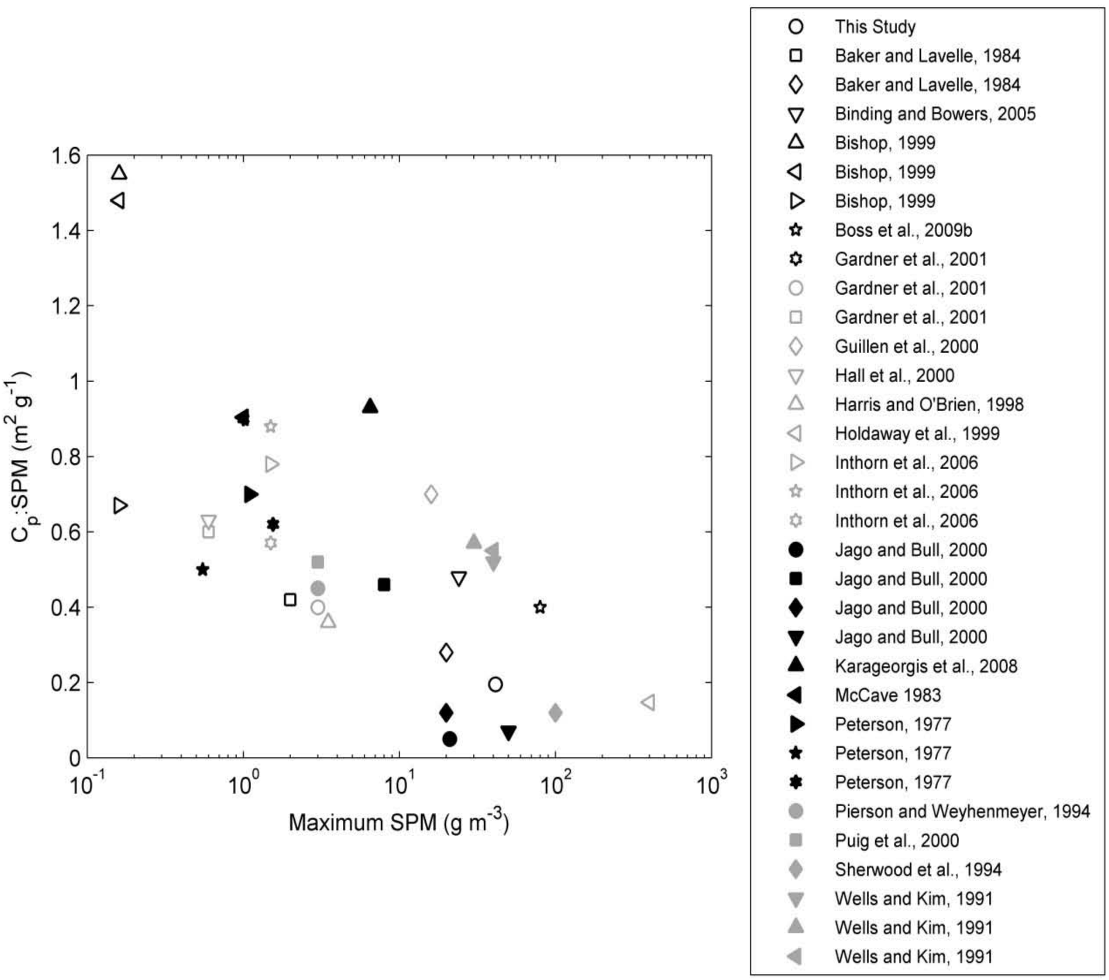

Figure 1. Literature values of mass normalized beam attenuation as function of the maximum particle mass measured during the study (from Hill et al., in press). The negative correlation can be explained by the fact that size and beam attenuation correlate in the environment. However, finite-acceptance-angle beam-transmissomters (of the type used in these studies), are less sensitive to large particle (which mostly scatter in the forward direction). Hence the more mass, the lower the ratio. The ratio is much more constant than one would predict based on Mie theory which can be explained by aggregation dynamics where particle surface area is approximately conserved.

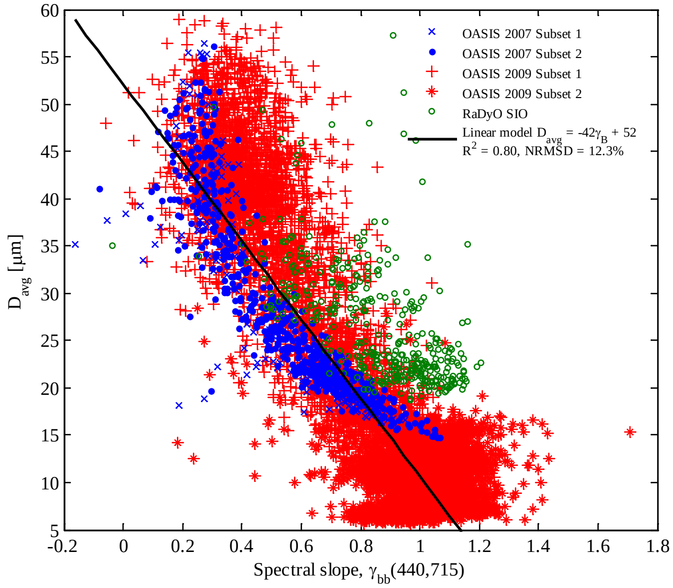

Figure 2. Mean LISST-based particles size as function of the ratio of backscattering at 440nm to that at 715nm. The smaller the ratio (flat spectra) the larger the mean particle. Data from several field campaigns.